RFA Simulation and Treatment Planning with a Haptic Device

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Abstract

The Radio Frequency Ablation Segmentation Tool (RFAST) is a prototype software application for treatment planning of radiofrequency ablation (RFA) procedures. Using a haptic force feedback system with the RFAST application interfaced to CT scans may enhance the 3D visual environment during RFA training and treatment planning. RFAST's infrastructure uses registration and fusion with multimodality images to augment the 3D visualizations of tumors and thermal treatment zones prior to and following RFA. The Phantom Omni haptic device is a robotic arm system that provides resistive force feedback to the stylus probe during the RFA simulation. Various tissue resistances to needle insertion is based upon corresponding CT Hounsfield Units (and density or attenuation of x-rays), therefore bone provides higher resistance than fat or lung tissues. The haptic device allows a physician to interactively position the RFA probe inside the 3D volume to determine the optimal insertion angle, skin entry point, and tip placement relative to patient-specific anatomy, for a potentially more precise tumor ablation. The user is able to feel this feedback as a spring force. RFA simulation and treatment planning system may be facilitated and improved with haptic feedback for the physician to provide a more realistic and patient specific treatment simulation with an enhanced 3D visual environment.

Introduction

We propose a RFA virtual environment that integrates haptic feedback technology using a Phantom Omni haptic device (SensAble Technologies; Woburn, MA) with 3D visualization of multi-modal image data for diagnostic purposes (Fig. 1). The user is able to use the Phantom Omni to interact with the virtual environment via a dummy probe mounted on the device arm so as to move the virtual probe against the virtual patient's anatomical model (Fig. 2). The software allows the physician to: (1) Explore the 3D data volume using a haptic force feedback device. (2) Simulate the RFA ablation procedure using the virtual probe after placed in the desired point in the volume. The ablated region can then be compared with the target tumor region. (3) Rotate the multi-planar orthogonal slice view in relation to the top of the needle probe's position and orientation, thus enabling the physician to view the 3D volume from a flexible viewing direction. (4) Differentiate the magnitudes of the resistive forces felt according to the tissues penetrated along the detecting path of the probe.

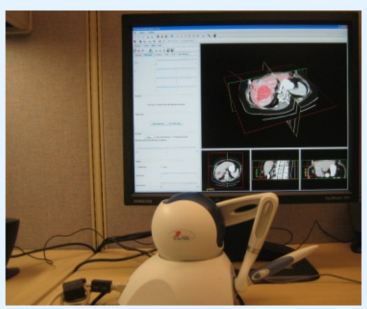

Figure 1. Phantom Omni haptic device

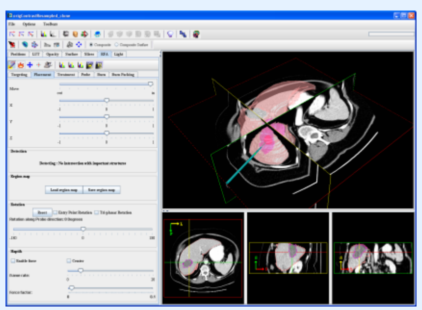

Figure 2. RFA virtual environment

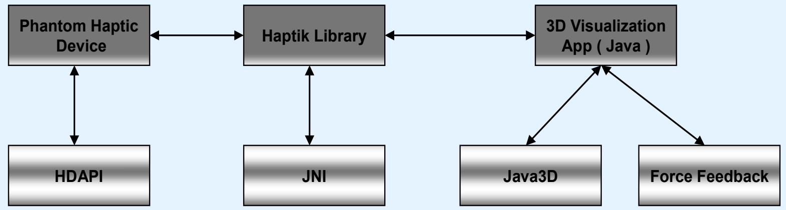

Figure 3. Infrastructure.

RFA Infrastructure Overview

The RFA virtual environment is built upon three major components (Fig. 3): the Phantom Omni, Haptik Library, and virtual rendering components. The Phantom Omni is a haptic device that can deliver resistive forces to the user through an electric motor, enabling force control and allowing the user to sense the resistance of different tissues through each virtual movement. The Haptic Device Application Program Interface (HDAPI) provides low-level access to the haptic device. It also provides the high-level rendering enabling programmers to render the force directly. The Haptik Library is a standalone software component, providing a hardware abstraction layer for access to haptic devices. It can accesses the HDAPI via a JNI interface and pass the end effector's position and force-related data information directly to the Java-based application, allowing the haptic device and Java-based application to communicate. The visualization component associates with the Graphic User Interface (GUI) to visualize, display, and interact with the graphical model of the examined tissue or organ. The visualization component composites from two sub-components, the Java3D-based rendering module and the force feedback module. The rendering module incorporates the multiplanar view, surface rendering, and volume rendering. The multiplanar view displays the 3D volume as three orthogonally intersected slices. The surface rendering visualizes the extracted surface (polygonal meshes) model for specific organs. The volume rendering uses a texture-based rendering scheme with histograms to visualize the 3D data volume. The force feedback module uses the data obtained from the haptik device to calculate the appropriate resistive force and then sends it back to the device controller, where the force is emulated.

Software Model

As the user interacts with the haptic device (Fig. 4), its sensors measure position, orientation, and force data, which are used to compute the feedback force in the computer simulation. A dedicated thread in the Haptik Library polls the device for this data using JNI and provides them to the Java simulation software. The simulation visualization then uses the position and orientation data to calculate the position of the virtual probe within the simulated environment. The software moves along the path of the virtual probe, checking the intensity in the image volume against the Hounsfield scale and the value in an isosurface of segmented tissue groups for each voxel. From these two sources, the software is able to determine the materials that the probe path intersects (such as bone, air, an organ, or vessels). This data can then be used to calculate the feedback force, which is to be applied to the haptic device. For simplicity, we use a spring damper force and a simple force filter to generate the stable force feedback. When a problematic intersection occurs along the probe's path, the spring force can be calculated according to Hooke's law:

$$F_{spring} = k * d = k * (x_1 - x_2)$$

where K = spring force factor, d = displacement

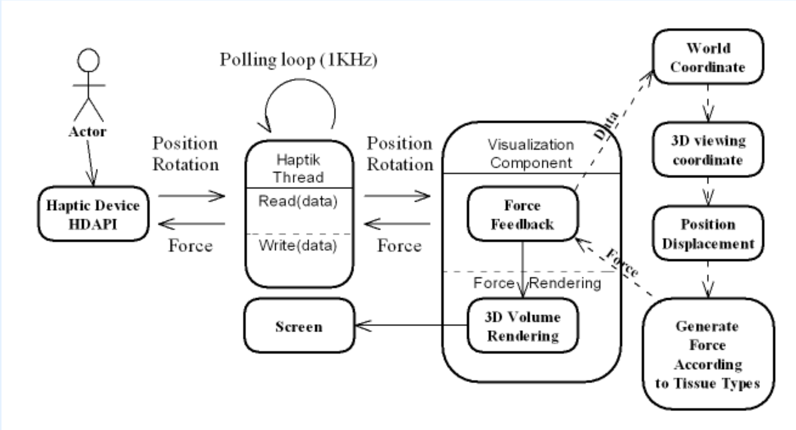

Figure 4.

The feedback force is generated at the point where the probe and tissue intersect. Utilizing this approach, we obtain more precise and stable force data for tissue collision detection. Even so, the force rendering may still lose continuity in touch sensation. Due to this fact, a force smoothing filter is applied to produce a more consistent force signal before sending it to the haptic device, thus a more stable force response is generated. Finally, the feedback force is sent back to the haptic device and displayed on the screen.

RFA Trainer Project

In order to design an effective virtual training system for RFA procedures, appropriate sensory information should be made available to the user. Normally the skills necessary to traverse a needle through various tissues are gained through direct contact experience. Incorporating accurate haptic feedback will provide for more realistic patient-specific training simulations and allow for a more practical transfer of skills from training to hands-on procedures. The physician will be allowed to interactively position the RFA probe inside the 3D volume to determine an optimal insertion angle, skin entry site, and tip placement relative to patient-specific anatomy.

Result and Future Work

The RFA virtual environment is implemented in a fully object-oriented structure that provides real-time interaction with the Phantom haptic device as a diagnostic tool for RFA simulation and training. Our project confirms the feasibility of RFA simulation and treatment planning with the Haptic device. The Phantom Omni device, however, has only 3 degrees-of-freedom (DOF). In the future, we want to generate true 6 DOF force feedback with a 6 DOF force feedback device, which would allow us to simulate more realistic force constraints and organ deformations. We want to provide user with a quality immersive impression, reinforces the sensation of realism with the RFAST simulation tool.

References

1. SensAble Technologies. www.sensable.com. Woburn, MA.
2. Haptik Library. www.haptiklibrary.org. University of Siena, Italy.

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